Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

INTRODUCTION

Bottom dwelling (i.e., demersal) fishes are collected as part of the South Bay Ocean Outfall (SBOO) monitoring program to assess the accumulation of contaminants in their tissues. The bioaccumulation of contaminants in a fish occurs through biological uptake and retention of chemical contaminants derived from various exposure pathways (Tetra Tech 1985). Exposure routes for demersal fishes include the adsorption or absorption of dissolved chemical constituents from the water and the ingestion and assimilation of pollutants from food sources. They also accumulate pollutants by ingesting pollutant-containing suspended particulate matter or sediment particles. Demersal fish are useful in biomonitoring programs because of their proximity to bottom sediments. For this reason, levels of contaminants in tissues of demersal fish are often related to those found in the environment (Schiff and Allen 1997).

The bioaccumulation portion of the SBOO monitoring program consists of 2 components: (1) liver tissues are analyzed from trawl-caught fishes; (2) muscle tissues are analyzed from fishes collected by rig fishing. Fishes collected from trawls are considered representative of the demersal fish community, and certain species are targeted based on their ecological significance (i.e., prevalence in the community). Chemical analyses are performed using livers of trawl-caught fishes because this is where contaminants typically concentrate due to the physiological role of this organ and the high lipid levels found there. In contrast, fishes targeted for collection by rig fishing represent a typical sport fisher's catch, and are therefore of recreational and commercial importance. Muscle tissue is analyzed from these fish because it is the tissue most often consumed by humans, and therefore the results are directly pertinent to human health.

All muscle and liver samples were analyzed for contaminants as specified in the NPDES discharge permits governing the SBOO monitoring program. Most of these contaminants are also sampled for the NOAA National Status and Trends Program. NOAA initiated this program to detect changes in the environmental quality of our nation's estuarine and coastal waters by tracking contaminants thought to be of concern for the environment (Lauenstein and Cantillo 1993). This chapter presents the results of all tissue analyses that were performed during 2005.

MATERIALS AND METHODS

Collection

Fishes were collected during the April and October surveys of 2005 at 7 trawl and 2 rig fishing stations (**Figure 7.1**). Trawl-caught fishes were collected, measured, and weighed following guidelines described in Chapter 6 of this report. Fishes targeted at the rig fishing sites were collected using rod and reel fishing tackle, and then measured and weighed

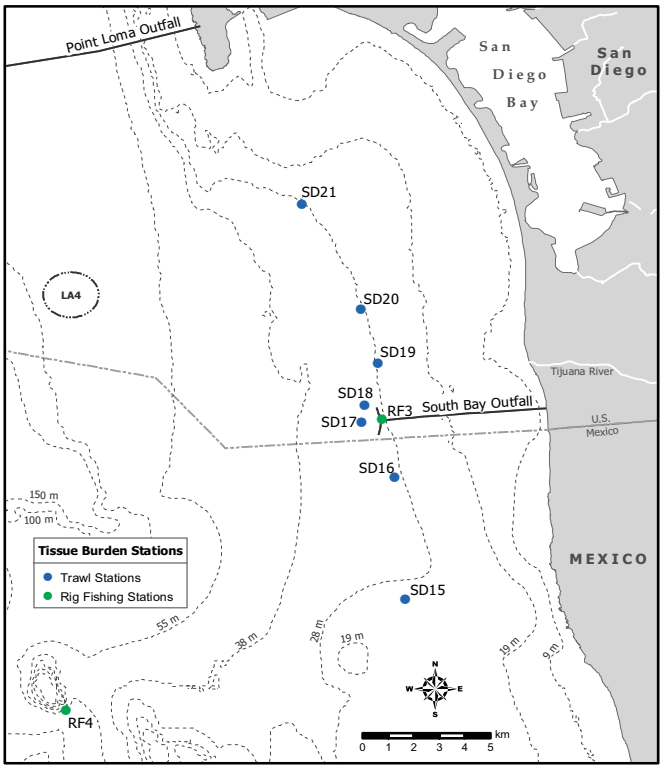

Figure 7.1
Otter trawl and rig fishing station locations for the South Bay Ocean Outfall Monitoring Program.

Table 7.1

Species collected at each SBOO trawl and rig fishing station during April and October 2005.

Station	Rep 1	Rep 2	Rep 3
April 2005			
SD15	English sole	Hornyhead turbot	California scorpionfish
SD16	Hornyhead turbot	California scorpionfish	English sole
SD17	English sole	Hornyhead turbot*	Longfin sanddab
SD18	Hornyhead turbot	California scorpionfish	English sole
SD19	Hornyhead turbot	English sole	Longfin sanddab
SD20	California scorpionfish	Hornyhead turbot	English sole
SD21	Longfin sanddab	Hornyhead turbot	English sole
RF3	Brown rockfish	Mixed rockfish	Brown rockfish
RF4	California scorpionfish	California scorpionfish	California scorpionfish
October 2005			
SD15	California scorpionfish	California scorpionfish	California scorpionfish
SD16	Hornyhead turbot	California scorpionfish	California scorpionfish
SD17	Hornyhead turbot	Hornyhead turbot	California scorpionfish
SD18	Hornyhead turbot	California scorpionfish	California scorpionfish
SD19	California scorpionfish	Hornyhead turbot	California scorpionfish
SD20	Hornyhead turbot	Hornyhead turbot	Hornyhead turbot
SD21	Hornyhead turbot	California scorpionfish	California scorpionfish
RF3	Brown rockfish	Vermilion rockfish	Vermilion rockfish
RF4	California scorpionfish	California scorpionfish	California scorpionfish

* missing all PAHs

following standard procedures (City of San Diego in prep). The species that were analyzed from each station are summarized in **Table 7.1**. The effort to collect targeted fishes at each trawl station was limited to five 10-minute trawls. Occasionally, insufficient numbers of target species were obtained despite this effort. Only fish >12 cm standard length were retained for tissue analyses. These fish were sorted into no more than 3 composite samples per station, each containing a minimum of 3 individuals. The fish were then wrapped in aluminum foil, labeled, put in ziplock bags, and placed on dry ice for transport to the Marine Biology laboratory freezer.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis (see City of San Diego in prep). Each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus prior to dissection. The standard length (cm) and weight (g) of each fish were recorded (**Appendix D.1**). Dissections were carried out on Teflon pads that were cleaned between samples. Tissue samples were then placed in glass jars, sealed, labeled, and stored in a freezer at -20 °C prior to chemical analyses. All samples were subsequently delivered to the City of San Diego Wastewater Chemistry Laboratory within seven days of dissection.

All tissue samples were analyzed for the chemical constituents specified by the permit under which this sampling was performed. These chemical constituents include trace metals, chlorinated pesticides, PCBs, and PAHs, and are listed in **Appendix D.2**. A summary of all parameters detected at each station during each survey is listed in **Appendix D.3**. Detected values for some parameters include those determined to be present in a sample with high confidence (i.e., peaks are confirmed by mass-spectrometry), but at levels

below the MDL. These are included in the data as estimated values. A detailed description of the analytical protocols may be obtained from the City of San Diego Wastewater Chemistry Laboratory (City of San Diego 2006).

RESULTS

Contaminants in Liver Tissues

Distribution among Species

Four species of fish comprised the 42 liver tissue samples collected in 2005. California scorpionfish and hornyhead turbot accounted for over 75% of the samples. Aluminum, arsenic, barium, cadmium, chromium, copper, iron, manganese, mercury, selenium, silver, and zinc occurred frequently in the liver tissues of all 4 species sampled (**Table 7.2**). Each metal was detected in over 85% of the samples. Arsenic, copper, iron, and zinc occurred at concentrations above 20 ppm in at least 1 sample. Iron had the highest mean concentration (>100 ppm), and had maximum values above 200 ppm in 3 of the 4 species, California scorpionfish, English sole, and longfin sanddab. Antimony, lead, nickel, thallium, and tin were also detected, but less frequently. Although tin was detected in 100% of the samples collected in 2004, it was detected in only 50% of the samples this year.

Several chlorinated pesticides were also detected in liver tissues (**Table 7.3**). Total DDT (the sum of 7 metabolites, see Appendix D.2) was found in all samples, with concentrations ranging from 75.9 ppb in hornyhead turbot to 2214 ppb in California scorpionfish. Other pesticides included chlordane, hexachlorobenzene (HCB), and BHC (Lindane). Of these, HCB was the most common, occurring in 86% of the samples with values less than 5 ppb. Detected components of chlordane included alpha (*cis*) Chlordane, gamma (*trans*) Chlordane, *cis*-Nonachlor, and *trans*-Nonachlor, each with concentrations less than 20 ppb.

PAHs were not detected in any samples collected in 2005. However, PCBs occurred in all samples for each species. Concentrations for the individual PCB congeners are listed separately in Appendix D.3. Total PCB concentrations (i.e., the sum of all congeners detected in a sample) were variable, ranging from about 28 ppb in an English sole sample to 756 ppb in a longfin sanddab sample. Mean concentrations were highest among longfin sanddabs and California scorpionfish at 577 ppb and 235 ppb, respectively.

Distribution among Stations

Concentrations of the frequently detected metals in fish liver tissues were fairly even across all stations (**Figure 7.2**). Most contaminant concentrations were close to or below the maximum levels detected in the same species prior to discharge. Only 15 of the 42 samples samples occurred at concentrations above their respective pre-discharge maximum. These samples involved only 4 metals (arsenic, mercury, iron, and zinc) and there was no pattern to how the samples were distributed among the 7 stations. Intraspecific comparisons between the 2 stations closest to the discharge (SD17, SD18) and those located farther away (SD15–SD16, SD19–SD21) suggest that there was no clear relationship between contaminant loads and proximity to the outfall.

As with metals, there was no clear relationship between concentrations of the frequently occurring pesticides (i.e., DDT, HCB, *trans*-Nonachlor), PCBs and proximity to the outfall (**Figure 7.3**). All values were below the maximum concentrations detected in the same species prior to discharge.

Contaminants in Muscle Tissues

Twelve composite samples of muscle tissue were collected from various rockfish species (**Tables 7.4, 7.5**). Aluminum, arsenic, barium, chromium, copper, iron, manganese, mercury, selenium, and zinc occurred frequently in the liver tissues of the species sampled (Table 7.4). Each of these metals was detected in over 75% of the samples. Antimony, cadmium, lead, nickel, silver, thallium, and tin were also detected, but less frequently. The metals with the highest mean concentrations included aluminum, arsenic, iron, thallium, and zinc. Each exceeded 2.5 ppm

Table 7.2

Metals detected in liver tissues from fishes collected at SBOO trawl stations during 2005. Values are expressed as parts per million (ppm); n=number of detected values, nd=not detected.

	Al	Sb	As	Ba	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Californa scorpionfish																	
N (out of 16)	13	9	16	16	15	12	16	16	11	16	15	5	16	13	12	4	16
Min	2.3	0.5	1.0	0.007	0.6	0.11	6.4	38	0.3	0.3	0.045	0.10	0.55	0.06	3.9	0.79	47
Max	18.0	1.0	3.8	0.316	3.4	0.47	25.7	239	0.9	0.6	0.440	0.21	1.00	0.99	5.3	1.09	158
Mean	8.5	0.8	2.7	0.041	1.6	0.24	13.9	138	0.6	0.4	0.146	0.14	0.73	0.31	4.7	0.96	84
Hornyhead turbot																	
N (out of 16)	15	3	16	14	16	15	16	16	9	16	16	5	16	13	9	7	16
Min	2.8	0.5	2.1	0.007	1.6	0.08	3.1	23	0.4	0.7	0.042	0.11	0.47	0.07	2.8	0.50	28
Max	11.8	0.6	4.7	0.042	6.2	1.23	8.2	84	0.8	2.0	0.145	0.31	1.07	0.31	3.8	0.69	66
Mean	7.5	0.5	3.4	0.026	3.6	0.31	5.6	44	0.6	1.3	0.085	0.22	0.67	0.17	3.4	0.57	40
English sole																	
N (out of 7)	7	nd	7	7	7	7	7	7	7	7	7	nd	7	7	nd	7	7
Min	8.6	—	9.5	0.029	0.8	0.16	3.9	132	0.4	0.9	0.018	—	1.09	0.16	—	0.46	28
Max	11.3	—	23.3	0.042	1.3	0.23	11.5	324	1.1	2.0	0.081	—	1.53	0.31	—	0.71	43
Mean	9.5	—	14.1	0.034	1.1	0.19	8.3	225	0.7	1.6	0.055	—	1.34	0.25	—	0.59	34
Longfin sanddab																	
N (out of 3)	3	nd	3	3	3	3	3	3	nd	3	3	nd	3	3	nd	3	3
Min	11.1	—	8.9	0.034	3.1	0.17	8.5	149	—	1.3	0.127	—	1.41	0.35	—	0.80	26
Max	16.2	—	22.0	0.054	5.8	0.27	13.0	213	—	2.1	0.195	—	1.63	0.59	—	0.95	28
Mean	14.2	—	17.2	0.047	4.4	0.22	10.5	182	—	1.6	0.161	—	1.54	0.44	—	0.87	27
ALL SPECIES																	
% Detected	90	29	100	95	98	88	100	100	64	100	98	24	100	86	50	50	100

Table 7.3

Chlorinated pesticides, total PCB, and lipids detected in liver tissues from fishes collected at SBOO trawl stations during 2005. A(C)C=alpha (*cis*) Chlordane, G(T)C=gamma (*trans*) Chlordane, CN=*cis*-nonachlor, TN=*trans*-Nonachlor, and HCB=hexachlorobenzene. Values are expressed in parts per billion (ppb) for all parameters except lipids, which are presented as percent weight (% wt), n=number of detected values, nd=not detected.

	Chlorinated Pesticides								
				Chlordane				Total	
	DDT	HCB	BHC	A(C)C	G(T)C	CN	TN	PCB	Lipids
California scorpionfish									
N (out of 16)	16	16	nd	15	nd	12	16	16	16
Min	152.1	0.9	—	2.7	—	2.8	4.6	115.0	17.2
Max	2213.5	2.0	—	5.5	—	6.2	13.0	511.5	32.0
Mean	642.1	1.3	—	3.8	—	4.1	7.8	235.1	22.3
Hornyhead turbot									
N (out of 16)	16	12	1	2	1	1	7	16	16
Min	75.9	0.4	3.3	3.2	2.2	3.1	1.8	30.6	4.9
Max	339.4	4.8	3.3	3.3	2.2	3.1	7.3	101.6	16.1
Mean	171.8	1.1	3.3	3.3	2.2	3.1	3.3	59.8	9.0
English sole									
N (out of 7)	7	5	nd	nd	nd	nd	1	7	7
Min	92.5	0.7	—	—	—	—	3.5	27.6	4.6
Max	1902.1	1.6	—	—	—	—	3.5	239.6	9.2
Mean	472.6	1.1	—	—	—	—	3.5	96.3	5.9
Longfin sanddab									
N (out of 3)	3	3	nd	3	nd	2	3	3	3
Min	668.0	1.2	—	3.6	—	4.3	6.6	393.7	14.0
Max	1371.9	1.6	—	5.6	—	4.3	15.0	755.6	15.9
Mean	1115.3	1.4	—	4.8	—	4.3	10.1	577.4	14.8
ALL SPECIES									
% Detected	100	86	2	48	2	36	64	100	

for at least 1 species of fish sampled; however there was little difference between the species relative to the concentrations for these metals.

DDT and PCBs were detected in 100% of the muscle samples, but at concentrations substantially lower than values detected in the livers of trawled fishes (even for the same species). Additional pesticides, including BHC (Lindane), HCB, and *trans*-Nonachlor (a component of Chlordane), were found much less frequently, and also at very low levels relative to concentrations found in liver tissues.

To address human health concerns, concentrations of the constituents found in muscle tissue samples were compared to national and international limits and standards (Tables 7.4, 7.5). The United States Food and Drug Administration (FDA) has set limits on the amount of mercury, total DDT, and Chlordane in seafood that is to be sold for human consumption (Mearns et al. 1991). In addition, there are international standards for acceptable concentrations of various metals (Mearns et al. 1991). While many compounds were detected in the muscle tissues of fish collected as part of the SBOO monitoring program, only arsenic and mercury had

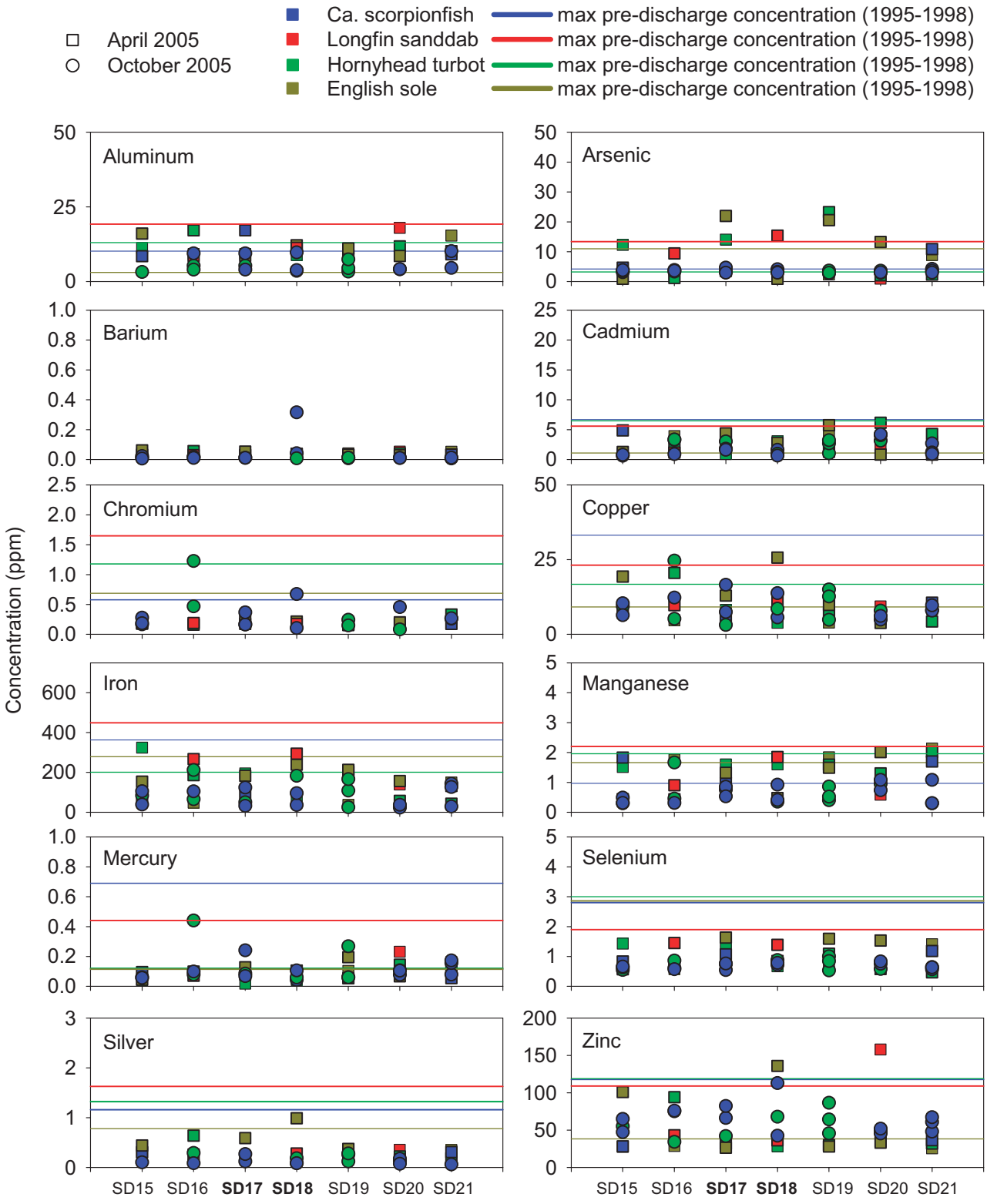

Figure 7.2

Concentrations of frequently detected metals in liver tissues of fishes collected from each SBOO trawl station during 2005. Reference lines are maximum values detected during the pre-discharge period (1995–1998). Stations closest to the discharge site are labeled in bold.

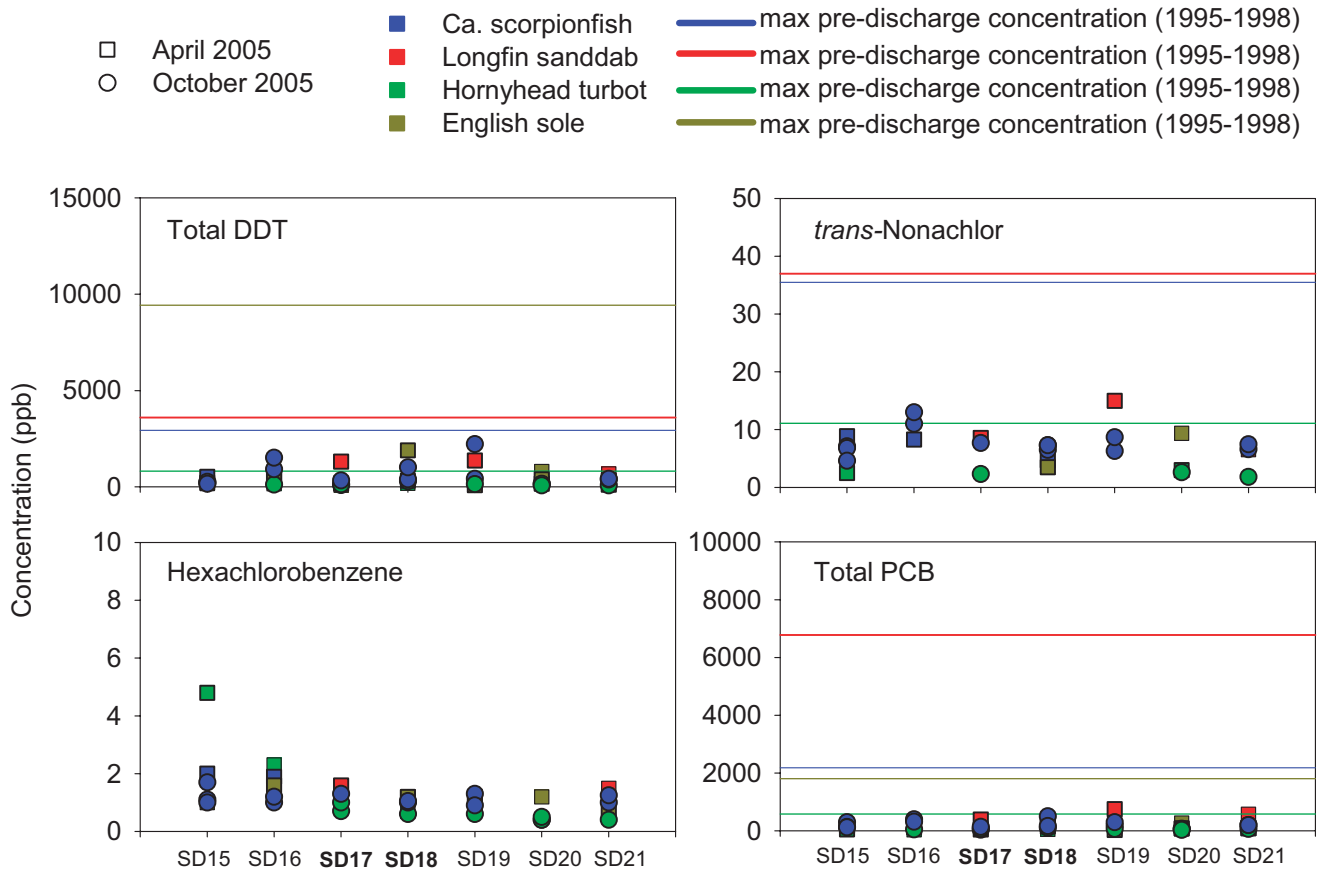

Figure 7.3

Concentrations of frequently detected chlorinated pesticides (total DDT, *trans*-Nonachlor, hexachlorobenzene) and total PCBs in liver tissues of fishes collected from each SBOO trawl station during 2005. Reference lines are maximum values detected during the pre-discharge period (1995–1998). Stations closest to the discharge site are labeled in bold.

concentrations that were higher than international standards.

In addition to addressing health concerns, spatial patterns were assessed for total DDT and total PCB, as well as all metals that occurred frequently in fish muscle tissue samples (**Figure 7.4**). Concentrations of metals, DDT, and PCB were variable in the muscle tissues of fishes from both rig fishing stations, and no clear relationship with proximity to the outfall was evident. Further, most samples had values close to or below the maximum concentrations detected in the same species prior to discharge. A notable exception is a high mercury value that exceeded the international standard, and was just below the US FDA action limit (see above). This sample came from California scorpionfish collected at station RF4 located near the Coronado Islands. California scorpionfish are known to travel over vast areas (Hartmann 1987, Love et al. 1987), so this high mercury level is most likely due to exposure from another area with higher levels of sediment contamination.

Comparison of contaminant loads between RF3 and RF4 should be considered with caution however, because different species of fish were collected at the 2 sites. Scorpionfish were collected at farfield station RF4 while rockfish were collected at nearfield station RF3. Both belong to the same family, Scorpaenidae, and have similar life histories (e.g., bottom dwelling tertiary carnivores), so they have similar mechanisms of exposure (e.g., exposure from direct contact with the sediments and through possibly similar food sources). These species are therefore comparable to a certain degree. However, since they are not the same species, differences in physiology and food choices may exist that could affect the accumulation of contaminants.

Table 7.4

Metals detected in muscle tissues from fishes collected at SBOO rig fishing stations during 2005. Data are compared to U.S. FDA action limits and median international standards for parameters where these exist. Bold values exceed these standards, n=number of detected values, nd=not detected.

	Al	Sb	As	Ba	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Brown rockfish																	
N (out of 3)	3	nd	3	2	nd	3	3	3	1	3	3	nd	3	2	1	2	3
Min	0.94	—	0.90	0.028	—	0.10	0.16	1.02	0.32	0.054	0.043	—	0.158	0.071	2.68	0.376	2.75
Max	6.99	—	**2.22**	0.033	—	0.14	1.40	2.36	0.32	0.071	0.209	—	0.245	0.083	2.68	0.549	3.60
Mean	4.87	—	1.35	0.030	—	0.12	0.59	1.78	0.32	0.060	0.128	—	0.204	0.077	2.68	0.463	3.16
California scorpionfish																	
N (out of 6)	5	nd	6	6	nd	4	6	6	3	6	6	1	6	3	3	3	6
Min	1.97	—	**1.77**	0.015	—	0.11	0.20	2.22	0.30	0.046	0.172	0.05	0.185	0.079	2.54	0.460	2.74
Max	9.13	—	**4.83**	0.047	—	0.13	1.39	3.88	0.38	0.080	**0.843**	0.05	0.257	0.089	2.74	0.602	3.98
Mean	5.90	—	**3.12**	0.029	—	0.12	0.62	2.92	0.35	0.063	0.295	0.05	0.227	0.083	2.66	0.539	3.38
Mixed rockfish																	
N (out of 1)	1	nd	1	1	nd	1	1	1	nd	1	1	nd	1	1	nd	1	1
Min	6.35	—	**1.93**	0.024	—	0.11	0.14	2.95	—	0.079	0.074	—	0.162	0.093	—	0.407	2.69
Max	6.35	—	**1.93**	0.024	—	0.11	0.14	2.95	—	0.079	0.074	—	0.162	0.093	—	0.407	2.69
Mean	6.35	—	**1.93**	0.024	—	0.11	0.14	2.95	—	0.079	0.074	—	0.162	0.093	—	0.407	2.69
Vermilion rockfish																	
N (out of 2)	1	1	2	2	nd	1	2	2	1	2	2	1	2	nd	2	nd	2
Min	4.17	0.49	**2.73**	0.004	—	0.81	0.27	1.21	0.44	0.101	0.054	0.73	0.275	—	2.87	—	3.01
Max	4.17	0.49	**2.88**	0.010	—	0.81	0.73	5.02	0.44	0.146	0.058	0.73	0.293	—	2.87	—	3.29
Mean	4.17	0.49	**2.81**	0.007	—	0.81	0.50	3.12	0.44	0.124	0.056	0.73	0.284	—	2.87	—	3.15
ALL SPECIES																	
% Detected	83	8	100	92	0	75	100	100	42	100	100	17	100	50	50	50	100
US FDA Action Limit*											1.0						
Median International Standard*			1.4		1.0	1.0	20		2.0		0.5		0.3			175	70.00

* From Mearns et al. 1991. FDA mercury action limits and all international standards are for shellfish, but are often applied to fish. All limits apply to the sale of seafood for human consumption.

Table 7.5

Total PCB, chlorinated pesticides, and lipids detected in muscle tissues from fishes collected at SBOO rig fishing stations during 2005. HCB=hexachlorobenzene and TN=*trans*-Nonachlor. Values are expressed in parts per billion (ppb) for all parameters except lipids, which are presented as percent weight (% wt); n=number of detected values, nd=not detected. Data are compared to U.S. FDA action limits and median international standards for parameters where these exist.

	Total PCB	Pesticides				Lipids
		DDT	BHC	HCB	TN	
Brown rockfish						
N (out of 3)	3	3	1	nd	nd	3
Min	0.50	1.0	0.7	—	—	0.24
Max	2.40	4.3	0.7	—	—	0.35
Mean	1.27	2.6	0.7	—	—	0.28
California scorpionfish						
N (out of 6)	6	6	nd	nd	nd	6
Min	0.50	3.0	—	—	—	0.24
Max	2.25	8.9	—	—	—	0.85
Mean	1.37	5.8	—	—	—	0.54
Mixed rockfish						
N (out of 1)	1	1	nd	nd	nd	1
Min	0.90	2.6	—	—	—	0.32
Max	0.90	2.6	—	—	—	0.32
Mean	0.90	2.6	—	—	—	0.32
Vermilion rockfish						
N (out of 2)	2	2	nd	1	1	2
Min	0.40	1.3	—	0.1	0.2	0.47
Max	2.00	4.7	—	0.1	0.2	1.63
Mean	1.20	3.0	—	0.1	0.2	1.05
ALL SPECIES						
% Detected	100	100	8	8	8	
US FDA Action Limit*		5000			300	
Median International Standard*		5000			100	

* From Mearns et al. 1991. FDA action limits for total DDT and Chlordane (of which *trans*-Nonachlor is a component) are for fish muscle tissue and all international standards are for shellfish, but are often applied to fish. All limits apply to the sale of seafood for human consumption.

SUMMARY AND CONCLUSIONS

Twelve trace metals, 2 pesticides, and a combination of PCBs were each detected in over 75% of the liver samples from 4 species of fish collected around the South Bay Ocean Outfall (SBOO) in 2005. All contaminant values were within the range of those reported previously for the Southern California Bight (SCB) (see Mearns et al. 1991, City of San Diego 1996–2001, Allen et al. 1998). Although the concentrations of several trace metals from several individual samples exceeded pre-discharge maximum values, concentrations of most contaminants were not substantially different from pre-discharge data (City of San Diego 2000b). In addition, the few samples that did exceed these pre-discharge values were distributed widely among the sampled stations and showed no pattern relative to the SBOO discharge.

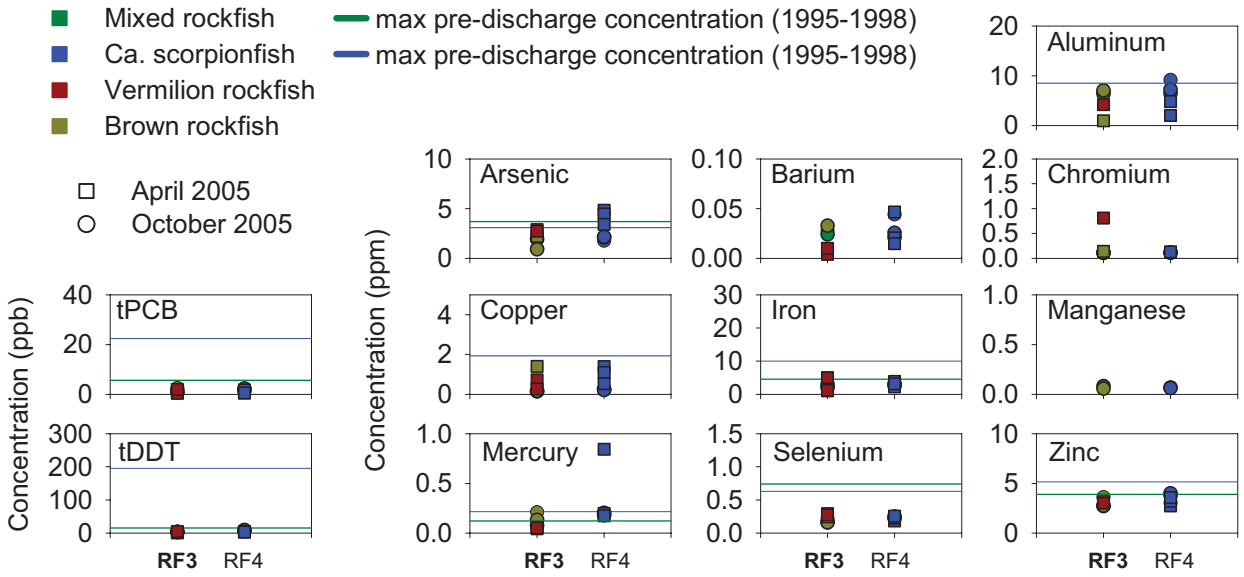

Figure 7.4

Concentrations of frequently detected metals, total DDT and total PCB in muscle tissues of fishes collected from each SBOO rig fishing station during 2005. Missing data represent concentrations below detection limits. Reference lines are maximum values detected during the pre-discharge period (1995-1998) for California scorpionfish and mixed rockfish. No vermilion or brown rockfish were collected during that period. Station RF3 is the station closest to the discharge site.

The frequent occurrence of metals and chlorinated hydrocarbons in SBOO fish tissues may be due to many factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the environment, although little information is available on their background levels in fish tissues. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998). The lack of contaminant-free reference areas in the SCB clearly pertains to the South Bay region, as demonstrated by the presence of many contaminants in fish tissues prior to wastewater discharge (City of San Diego 2000b).

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history of different fish species. For example, exposure to contaminants can vary greatly between species and among individuals of the same species depending on migration habits (Otway 1991). Fish may be exposed to contaminants in one highly contaminated area and then move into an area that is less contaminated. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many point and non-point sources that may contribute to contamination in the region. For example, some monitoring stations are located near the Tijuana River, San Diego Bay, and dredged materials disposal sites, and input from these sources may affect fish in nearby areas.

Overall, there was no evidence that fishes collected in 2005 were contaminated by the discharge of waste water from the SBOO. While some muscle tissue samples from sport fish collected in the area had concentrations of arsenic and mercury above the median international standard for shellfish, concentrations of mercury and DDT were below FDA human consumption limits. Finally, there was no other indication of poor fish health in the region, such as the presence of fin rot or other physical anomalies (see Chapter 6).

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